

**MAGNETIC SHIELDING DEVICES AND METHODS INVOLVING  
ACTIVE CANCELLATION OF EXTERNAL MAGNETIC FIELDS AT THE  
COLUMN OF A CHARGED-PARTICLE-BEAM OPTICAL SYSTEM**

5

**Field**

This disclosure pertains, *inter alia*, to microlithography, which is a key technology employed in the fabrication of microelectronic devices such as integrated circuits, displays, thin-film magnetic pickup heads, and micromachines. More specifically, the disclosure pertains to microlithography performed using a charged particle beam such as an electron beam or ion beam. Even more specifically, the disclosure pertains to apparatus and methods for achieving magnetic shielding of a charged-particle-beam (CPB) optical system as used, e.g., in a CPB microlithography system, especially magnetic shielding that achieves satisfactory cancellation of magnetic fields external to a column containing the CPB optical system and/or of magnetic fields flowing on the outer skin of the column that otherwise would penetrate into the column and interfere with the trajectory of the charged particle beam in the column.

10

15

**Background**

20 Because a charged particle beam (e.g., electron beam or ion beam) cannot be transmitted satisfactorily through air, charged-particle-beam (CPB) optical systems are encased in a "column" that is evacuated to a suitably high vacuum. The column normally is contiguous with a vacuum chamber in which other components, such as a stage on which a lithographic substrate (e.g., semiconductor wafer) is mounted. In 25 conventional CPB microlithography systems, the problem of magnetically shielding the CPB optical system is well known, and various approaches have been considered for achieving satisfactory protection of the CPB optical system inside the column from being adversely affected by external static and dynamic magnetic fields.

30 In one conventional approach, the column and vacuum chamber are enclosed in one or multiple layers of a material having a high initial permeability (such as one

of the Permalloys). In addition, the column and/or vacuum chamber itself is made of Permalloy.

An example of an electron-beam microlithography apparatus having conventional magnetic shielding is shown in FIG. 9. The apparatus of FIG. 9

5 comprises column 11 encasing an electron-optical system (not detailed). The column 11 is contiguous with a vacuum chamber 12. The respective interiors of the column 11 and vacuum chamber 12 are evacuated by a vacuum pump (not shown) connected to a vacuum port 13. Inside the column 11 is an electron source 14 (e.g., electron gun) that produces an electron beam 15. The electron beam 15 is shaped  
10 and deflected as required by electron lenses and deflectors (not shown but well understood in the art) of the electron-optical system. Inside the vacuum chamber 12 is a substrate stage 16. Situated externally to the column 11 and vacuum chamber 12 is a magnetic shield 17 made of a material having a high initial permeability.

15 The column 11 typically defines various openings 18 to allow access inside the column for, e.g., evacuating the column (and vacuum chamber 12), making electrical connections to components (e.g., lenses and deflectors of the electron-optical system) inside the column 11, and for moving articles into and out of the column and vacuum chamber. In a system configuration as shown in FIG. 9, corresponding openings 19 also are defined in the magnetic shield 17. Having to  
20 provide these openings 19 in the shield 17 results in the shield 17 being divided into multiple segments or portions. These openings 18, 19 as well as any non-magnetic portions of the column 11 define respective "gaps" through which a stray or external magnetic field can enter the column. As used herein, the term "opening" encompasses any of various physical openings as well as any of various gaps.

25 Dividing the shield 17, having to define openings 19 in it, or otherwise providing gaps in the shield 17 inevitably degrade its shielding properties. Thus, in conventional systems utilizing this approach, it simply is not possible to provide a suitably high level of shielding, especially for a CPB optical system for use in a CPB microlithography apparatus. According to a conventional approach for improving  
30 the magnetic isolation of the charged particle beam inside the column, the entire room or area in which the CPB microlithography system is placed is completely

enclosed in magnetic-shielding material, thereby forming a "shielded room."

Simply shielding a room in this manner represents a "passive" approach to room shielding.

In the shielded-room approach, the actual room shielding can be "active,"

- 5 wherein coils (capable of generating respective magnetic fields in desired directions) are placed at a distance (e.g., in or on room walls) from the column and vacuum chamber. By selectively adjusting the magnitude and direction of electrical current delivered to individual coils, the coils produce respective magnetic fields that "cancel" the external magnetic fields. A magnetic-shielding device employing coils
- 10 in this manner is referred to as an "active canceler." An example of a conventional active canceler is shown in FIG. 10, comprising three pairs of coils 21 and 21', 22 and 22', and 23 and 23', each indicated by a respective circle in the figure. Each coil is associated with a respective wall of a room or analogous space. The arrows associated with each circle denote the respective direction of electrical current
- 15 flowing in the respective coil. Thus, the three pairs of coils 21 and 21', 22 and 22', and 23 and 23' generate three respective magnetic fields oriented in respective mutually perpendicular directions. The individual electrical currents applied to the coils can be adjusted as required to obtain, in the active canceler, respective magnetic fields of the proper magnitude and direction to cancel the external fields.

- 20 Unfortunately, in the conventional active-canceler scheme summarized above, in which the column is covered with magnetic-shielding material, the constraints imposed by the need to define openings and/or gaps in the shielding material and/or by the need to divide the shielding into multiple portions make it impossible to achieve adequate shielding. Also, whenever the column is situated in
- 25 a poor magnetic environment, or whenever the column is especially sensitive to external magnetic fields, double or triple shielding must be used in addition to placing the CPB microlithography apparatus in a shielded room. Such extensive shielding greatly increases both the mass of the CPB microlithography system and the floor area required to accommodate the system, which substantially increases
- 30 cost.

The conventional active-canceler approach summarized above is effective for shielding a CPB microlithography system having a simple shape, such as a simple cylinder. However, CPB microlithography systems typically have more complex shapes. Furthermore, the external magnetic field often is highly non-uniform. Under either or both these conditions, the conventional active-canceler approach has limited utility in achieving satisfactory cancellation of external magnetic fields, and thus is incapable of reducing external magnetic fields in the column to within specifications. As a result, obtaining a desired magnetic-field distribution within the column is extremely difficult.

10

### Summary

In view of the shortcomings of conventional apparatus and methods as summarized above, an object of the invention is to provide magnetic shielding methods and devices, as used especially in charged-particle-beam (CPB) microlithography systems and other systems that utilize a CPB optical system, for canceling the effects within the CPB optical system of otherwise interfering external magnetic fields. The subject methods and devices can be used in systems in which the column and/or chamber of the CPB optical system has a complex shape, and/or under conditions in which the external magnetic fields are highly non-uniform.

To such end, and according to a first aspect of the invention, methods are provided for magnetically shielding a CPB optical system situated inside a column that extends along an optical axis. In an embodiment of such a method one step involves disposing, at an axial position relative to the column, an active-canceler coil "set" adjacent a wall of the column so as not to obstruct a trajectory of a charged particle beam propagating in the column. The coil set can comprise as few as one coil or can comprise multiple individual coils that are individually electrically energizable. Another step involves electrically energizing the coil(s) so as to cause the coil set to produce a respective magnetic field of a desired direction and magnitude effective for canceling an external magnetic field or a magnetic flux, present externally to the column, that otherwise would extend from outside the column to the optical axis. Thus, a distribution of magnetic field within the column

is corrected to a desired distribution. In the method, if the column defines a lateral opening (or other "gap" such as a region of non-magnetic material in the column), then the coil set desirably is disposed adjacent the opening.

If the coil set referred to above is regarded as a first coil set, then the method

- 5 summarized above can further include disposing a second active-canceler coil "set" adjacent the opening opposite the first coil set so as not to obstruct the trajectory of a charged particle beam propagating in the column. The second coil set can comprise a single coil or can comprise multiple individual coils that are individually electrically energizable. While electrically energizing the coil(s) of the first coil set,
- 10 the coil(s) of the second coil set are electrically energized so as to cause the coil sets to collectively produce a magnetic field of a desired direction and magnitude effective for canceling the external magnetic field.

The individual coil(s) of the coil set(s) can have any of various geometrical configurations. By way of example, each of the individual coils can be circular or

- 15 rectilinear in configuration.

The coil set(s) can be situated in respective transverse plane(s) perpendicular to the optical axis or in respective plane(s) that are oblique relative to the optical axis.

- 20 By placing the coil(s) of a coil set at the same axial position relative to the column and by energizing the coil(s) with respective prescribed electrical currents, the magnitude and direction of the composite magnetic field generated by the coil(s) are controlled so as to controllably reduce penetration of an external magnetic field (or a magnetic flux on or near the outer surface of the column) into the optical path of the charged particle beam in the column. Desirably, the magnitude and direction 25 of the interfering magnetic field(s) (e.g., the external field or the flux along the outer surface of the column) are measured, and the respective electrical currents in the individual coil(s) are adjusted as required to form a composite field that cancels the external field(s).

- 30 Interfering magnetic fields usually exhibit variation in the axial direction of the column. Hence, it is desirable to provide multiple coil sets at different respective

axial positions relative to the column to allow cancellation of interfering magnetic fields at the various axial locations.

Because very precise cancellation of external fields can be achieved, the effects of interfering external magnetic fields can be adequately cancelled, even

5 whenever the distribution of the interfering magnetic field is not uniform. Also, because this cancellation is achieved using coils, no extra space is required for shielding. This reduces the amount of space occupied by the CPB optical system and reduces the mass of the system.

It is noted that "cancellation" per se, as used herein, does not necessarily  
10 mean totally reducing the interfering field to zero magnitude. Rather, "cancellation" includes any reduction of the effects of the interfering magnetic field(s) at target locations to levels that will not pose problems with the system configuration.

In another method embodiment, one step involves disposing, at an axial position relative to the column and adjacent the opening (or other "gap"), an active-  
15 canceler coil set adjacent a wall of the column so as not to obstruct a trajectory of a charged particle beam propagating in the column. The coil set comprises at least one coil that is electrically energizable. In another step, a magnetic shield is disposed externally to the column. The magnetic shield desirably is made of an anisotropic magnetic material. The at least one coil is electrically energized so as to  
20 cause the coil set to produce a respective magnetic field of a desired direction and magnitude effective for canceling an external magnetic field or a magnetic flux, present externally to the column, that otherwise would extend from outside the column through the opening to the optical axis. Thus, a distribution of magnetic field within the column is corrected to a desired distribution. In this method  
25 embodiment, the coil(s) can have any of various respective configurations such as any of the specific configurations as summarized above. Furthermore, the magnetic shield desirably is magnetically partitioned, with the partitions desirably extending in the axial direction.

If anisotropic magnetic material is used for the magnetic shield, then the  
30 direction of the external (and possibly interfering) magnetic field can be altered to align its direction with the direction of the magnetic field generated by the coils. As

a result, controlling the respective electrical currents applied to the coils to achieve the desired cancellation is correspondingly made easier, even whenever the shape of the CPB optical system is complex and/or the external magnetic field(s) is highly non-uniform.

5        In practice, the coil set(s) and the anisotropic direction and location of the magnetic shield material are determined such that the direction and magnitude of the external magnetic field are opposite the direction and magnitude of the composite magnetic field produced by the electrical currents flowing through the respective coils.

10      According to yet another method embodiment, at least one active-canceler coil set is situated on or near the column so as not to obstruct a trajectory of a charged particle beam propagating in the column. Each coil set is configured, when electrically energized, to produce a respective magnetic field oriented in a prescribed direction. The at least one coil set is electrically energized to cause the coil set to

15      produce the respective magnetic field having a magnitude sufficient to cancel at least a portion of a target magnetic field, external to the column, that otherwise would penetrate through the column to the optical axis. The at least one coil set can be oriented relative to the column to produce a respective magnetic field having a direction parallel to the optical axis, perpendicular to the optical axis, or oblique

20      relative to the optical axis.

Yet another embodiment is directed to a method for magnetically shielding a CPB system comprising a CPB column and at least one chamber situated relative to an optical axis. In the method, at an optical axial position relative to the system, at least one active canceler coil is disposed adjacent a wall of the system so as not to obstruct a trajectory of a charged particle beam propagating in the system. The at least one coil is electrically energized so as to cause the coil to produce a magnetic field. The produced magnetic field cancels at least a portion of an external magnetic field or a magnetic flux, present externally to the system and that otherwise would extend from outside to inside the system to the optical axis within the system, to a desired distribution. If the system defines a magnetic gap (which can be an opening in the CPB column), then the coil(s) desirably is defined adjacent the magnetic gap.

This method embodiment can include the step of disposing a magnetic shield externally to the system. The magnetic shield desirably is made of an anisotropic magnetic material, and can be magnetically partitioned into partitions. If the shield is partitioned, the partitions can extend, for example, in an axial direction. The

5 magnetic shield can be disposed so as to place the magnetic flux, present externally to the system, in a desired direction along the optical axis.

The coil(s) can be oriented relative to the column to produce a respective magnetic field having any of various directions, such as parallel to the optical axis, obliquely to the optical axis, or perpendicular to the optical axis. If multiple coils are used,

10 they can be positioned so as to position the optical axis within each coil or outside each coil.

According to another aspect of the invention, devices are provided, in the context of a CPB optical system situated inside a column, for reducing (by cancellation) a magnetic field external to the column that otherwise would extend to 15 inside the column. Thus, the CPB optical system is magnetically shielded from the external magnetic field. An embodiment of such a device comprises an active-canceler coil set situated at an axial position relative to the column and adjacent a wall of the column so as not to obstruct a trajectory of a charged particle beam propagating in the column. The coil set comprises at least one electrically

20 energizable coil that produces, when electrically energized, a respective magnetic field of a direction and magnitude sufficient for canceling at least a portion of the external magnetic field. In this device embodiment, the coil(s) can have any of various configurations such as those summarized above.

In another embodiment, a magnetic-field-canceling device comprises an active-canceler coil set situated at an axial position relative to the column and adjacent a wall of the column so as not to obstruct a trajectory of a charged particle beam propagating in the column. The coil set comprises at least one coil that, when electrically energized, produces a respective magnetic field of a direction and magnitude sufficient for canceling at least a portion of the external magnetic field.

30 The device also includes a magnetic shield, desirably made of an anisotropic magnetic material, situated outside the column. In this device embodiment, the

coil(s) can have any of various specific configurations, as summarized above. Also, the device can include multiple coil sets. Furthermore, the magnetic shield can be magnetically partitioned, with the partitions desirably extending in the axial direction. Partitioning allows better alignment of the direction of the external

5 magnetic field with the direction of the magnetic field formed by the respective currents flowing in the coils.

In yet another embodiment, the device comprises at least one active-canceler coil set situated on or near the column so as not to obstruct a trajectory of a charged particle beam propagating in the column. Each coil set is configured to be

10 electrically energized and, when electrically energized, to produce a respective magnetic field oriented in a prescribed direction and having a magnitude sufficient to cancel at least a portion of the external magnetic field. The at least one coil set is oriented relative to the column to produce a respective magnetic field having a direction that is parallel to the optical axis, perpendicular to the optical axis, or  
15 oblique relative to the optical axis. This device can include a magnetic shield, as summarized above.

Yet another embodiment is directed to a device for magnetically shielding a CPB system comprising a CPB column and at least one chamber situated relative to an optical axis. At an optical axial position relative to the system, at least one active  
20 canceler coil is disposed adjacent a wall of the system so as not to obstruct a trajectory of a charged particle beam propagating in the system. The at least one coil is electrically energizable so as to cause the coil to produce a magnetic field. The produced magnetic field cancels at least a portion of an external magnetic field or a magnetic flux, present externally to the system and that otherwise would extend  
25 from outside to inside the system to the optical axis within the system, to a desired distribution. If the system defines a magnetic gap (which can be an opening in the CPB column), then the coil(s) desirably is defined adjacent the magnetic gap.

The device can include a magnetic shield disposed externally to the system. The magnetic shield desirably is made of an anisotropic magnetic material, and can  
30 be magnetically partitioned into partitions. If the shield is partitioned, the partitions can extend, for example, in an axial direction. The magnetic shield can be disposed

so as to place the magnetic flux, present externally to the system, in a desired direction along the optical axis.

The coil(s) can be oriented relative to the column to produce a respective magnetic field having any of various directions, such as parallel to the optical axis,

5 obliquely to the optical axis, or perpendicular to the optical axis. If multiple coils are used, they can be positioned so as to position the optical axis within each coil or outside each coil.

In any of the various device embodiments according to the invention one or more magnetic sensors can be employed for sensing the magnitude and direction of

10 an external magnetic field. For example, a magnetic sensor can be situated at a location where a magnetic field having zero magnitude is required or desired.

Respective electrical currents supplied to individual coils of a coil set(s) can be controlled, based on feedback from the sensor(s), to achieve the goal of complete cancellation of the external magnetic field.

15 According to another aspect of the invention, CPB microlithography apparatus are provided that include a device as summarized above.

The foregoing and additional features and advantages of the invention will be more readily apparent from the following detailed description, which proceeds with reference to the accompanying drawings.

20

#### Brief Description of the Drawings

FIG. 1(a) is an elevational section of a column and contiguous vacuum chamber of a CPB optical system that includes a first representative embodiment of a device for canceling an external magnetic field.

25 FIGS. 1(b) and 1(c) are respective transverse sections of the column of FIG. 1(a), showing respective configurations of active-canceler coil sets each comprising multiple individual coils situated outside the column.

FIG. 2(a) is an elevational section of the column and contiguous vacuum chamber of a CPB optical system that includes a second representative embodiment 30 of a device for canceling an external magnetic field.

FIGS. 2(b) and 2(c) are respective transverse sections of the column of FIG. 2(a), showing respective configurations of active-canceler coil sets each comprising multiple individual coils situated inside the column.

FIG. 3(a) is an elevational section of the column and contiguous vacuum chamber of a CPB optical system that includes a third representative embodiment of a device for canceling an external magnetic field.

FIGS. 3(b)-3(c) are respective transverse sections of the column of FIG. 3(a), showing respective configurations of active-canceler coil sets each comprising multiple individual coils situated inside the column.

FIG. 4 is an elevational section of the column and contiguous vacuum chamber of a CPB optical system that includes a fourth representative embodiment of a device for canceling an external magnetic field.

FIG. 5 is an oblique view of external magnetic shielding around a column and vacuum chamber, according to a fifth representative embodiment.

FIG. 6 is an elevation section of the column and vacuum chamber of a CPB optical system that includes a sixth representative embodiment of a device for canceling an external magnetic field.

FIG. 7(a) is an elevational section of the column and vacuum chamber of a CPB optical system that includes a seventh representative embodiment of a device for canceling an external magnetic field.

FIG. 7(b) depicts a plan view (in the x-y plane) and an elevational view (in the y-z plane) of a coil of the coil set 105 shown in FIG. 7(a).

FIG. 7(c) is an oblique view of the coil shown in FIG. 7(b).

FIG. 8 is an elevational section of the column and vacuum chamber of a CPB optical system that includes an eighth representative embodiment of a device for canceling an external magnetic field.

FIG. 9 is an elevational section of a column and contiguous vacuum chamber that include external magnetic shielding according to a conventional shielding scheme.

FIG. 10 is an oblique view of certain aspects of a conventional active-canceler scheme for shielding a room or analogous space containing a CPB optical system.

5

### Detailed Description

Various aspects of the invention are described below in the context of representative embodiments, which are not intended to be limiting in any way.

#### First Representative Embodiment

10 Magnetic shielding according to this embodiment is described with reference to FIGS. 1(a)-1(c), which depict an electron-optical system (as a representative CPB optical system). Similar to the configuration shown in FIG. 9, the embodiment of FIG. 1(a) comprises a column 31 that contains an electron-optical system (not shown) comprising, e.g., electron lenses and deflectors.

15 Contiguous with the column 31 is a vacuum chamber 32 that, together with the column 31, is connected to a vacuum pump (not shown) via a vacuum port 33. The column 31 comprises multiple portions 31a, 31b and defines various openings 34 at which external magnetic fields (indicated by arrows 35) can leak into the column 31. The openings 34 can be actual physical openings or "gaps" defined 20 by respective regions of non-magnetic material through which stray or external magnetic fields can enter the column 31. Whereas these external fields could disrupt the trajectory of the electron beam in the column 31, they are prevented from having such an effect by active-canceler coil sets 36 (e.g., a total of five coil sets) placed proximally to the openings 34.

25 Exemplary coil sets 36a and 36b are shown in FIGS. 1(b) and 1(c), respectively. Each of FIGS. 1(b) and 1(c) is a respective view along the longitudinal axis A of the column 31, which results in the column 31 being viewed as a transverse section. The coil set 36a shown in FIG. 1(b) comprises four individual circular coils 36a<sub>1</sub>-36a<sub>4</sub>. The coils 36a<sub>1</sub>-36a<sub>4</sub> are situated at the same position along 30 the axis A of the column 31 and are situated outside and encircle the column 31. The center of each coil 36a<sub>1</sub>-36a<sub>4</sub> is laterally displaced from the center of the column

31, wherein the respective centers of the coils 36a<sub>1</sub>-36a<sub>4</sub> are situated on a circle 38 equi-angularly (90° in the depicted configuration) relative to each other. The circle 38 is concentric with the longitudinal axis A. Each of the coils 36a<sub>1</sub>-36a<sub>4</sub> has a respective pair of wires 37 extending therefrom. To minimize external effects of

5 magnetic fields generated by the currents flowing therein, each pair of wires 37 is twisted. As an alternative to twisted pairs of wires 37, shielded cable or twisted pairs with shielding could be used.

Because the four coils 36a<sub>1</sub>-36a<sub>4</sub> are situated with offset centers as noted above, the magnitude and direction of the composite magnetic field generated by the 10 set of coils 36a can be finely varied over a wide range by adjusting the respective electrical current flowing in each individual coil 36a<sub>1</sub>-36a<sub>4</sub>. Thus, a composite magnetic field can be generated having a magnitude and direction sufficient to cancel an otherwise interfering external magnetic field, thereby canceling the effect of the external magnetic field.

15 In the coil set 36b shown in FIG. 1(c), each of the individual coils 36b<sub>1</sub>-36b<sub>4</sub> has an oblong configuration. However, the operational result of the coil set 36b is the same as of the coil set 36a in FIG. 1(b).

#### Second Representative Embodiment

20 Magnetic shielding according to this embodiment is described with reference to FIGS. 2(a)-2(c), which depict an electron-optical system (as a representative CPB optical system). Similar to the first representative embodiment, the embodiment of FIG. 2(a) comprises a column 41 that contains an electron-optical system (not shown). Contiguous with the column 41 is a vacuum chamber 42 that, together with the column 41, is connected to a vacuum pump (not shown) via a vacuum port 43.

The column 41 defines various openings (or gaps) 44 at which external magnetic fields (indicated by arrows 45) can leak into the column 41. Whereas these external fields could disrupt the trajectory of the electron beam in the column 41, they are prevented from having such an effect by active-canceler coil sets 46 (e.g., a total of five coil sets placed in a manner similar to the first representative embodiment).

Exemplary coil sets 46a and 46b are shown in FIGS. 2(b) and 2(c), respectively. Each of FIGS. 2(b) and 2(c) is a respective view along the longitudinal axis A of the column 41, which results in the column 41 being viewed as a transverse section. The coil set 46a shown in FIG. 2(b) comprises four individual 5 circular coils 46a<sub>1</sub>-46a<sub>4</sub>. The coils 46a<sub>1</sub>-46a<sub>4</sub> are situated inside the column 41 at the same position along the axis A. The center of each coil 46a<sub>1</sub>-46a<sub>4</sub> is laterally displaced from the center of the column 41, wherein the respective centers of the coils 46a<sub>1</sub>-46a<sub>4</sub> are situated equi-angularly (90° in the depicted configuration) 10 relative to each other. Each of the coils 46a<sub>1</sub>-46a<sub>4</sub> has a respective pair of wires 47 extending therefrom. To minimize external effects of magnetic fields generated by the currents flowing therein, each pair of wires 47 is twisted, as discussed in the first 15 representative embodiment.

Because the four coils 46a<sub>1</sub>-46a<sub>4</sub> are situated with offset centers as noted above, the magnitude and direction of the composite magnetic field generated by the 15 set of coils 46a can be finely varied over a wide range by adjusting the respective electrical current flowing in each individual coil 46a<sub>1</sub>-46a<sub>4</sub>. Thus, a composite magnetic field can be generated having a magnitude and direction sufficient to cancel an otherwise interfering external magnetic field, thereby canceling the effect 20 of the external magnetic field.

In the coil set 46b shown in FIG. 2(c), each of the individual coils 46b<sub>1</sub>-46b<sub>4</sub> has an oblong configuration. However, the operational result of the coil set 46b is the same as of the coil set 46a in FIG. 2(b).

The placement of coils in the configurations of FIGS. 2(b) and 2(c) shares many similarities to the placement scheme of the first representative embodiment, 25 except that, in the first representative embodiment the coils 36 are outside the column 31, and in the second representative embodiment the coils 46 are inside the column 41. Nevertheless, so long as the active-canceler coils 46 do not obstruct the trajectory of the electron beam, the placement of coils 46 as shown in FIGS. 2(b) and 2(c) functions as well as the placement of coils 36 in FIGS. 1(b) and 1(c). Also, 30 by mounting the coils 46 inside the column 41 according to the second representative embodiment, the respective magnetic fields generated by the coils 46

are not impeded by having to pass through the column 41. As a result, smaller currents can be applied to the coils 46 to control the composite magnetic field.

#### Third Representative Embodiment

5 Magnetic shielding according to this embodiment is described with reference to FIGS. 3(a)-3(c), which depict an electron-optical system (as a representative CPB optical system). Similar to the first representative embodiment, the embodiment of FIG. 3(a) comprises a column 51 that contains an electron-optical system (not shown). Contiguous with the column 51 is a vacuum chamber 52 that, together with 10 the column 51, is connected to a vacuum pump (not shown) via a vacuum port 53.

The column 51 defines various openings (or gaps) 54 at which external magnetic fields (indicated by arrows 55) can leak into the column 51. Whereas these external fields could disrupt the trajectory of the electron beam in the column 51, they are prevented from having such an effect by active-canceler coil sets 56 15 (e.g., a total of five coil sets placed in a manner similar to the first representative embodiment).

Exemplary coil sets 56a and 56b are shown in FIGS. 3(b) and 3(c), respectively. Each of FIGS. 3(b) and 3(c) is a respective view along the longitudinal axis A of the column 51, which results in the column 51 being viewed as a 20 transverse section.

The coil set 56a shown in FIG. 3(b) comprises four individual oblong coils 56a<sub>1</sub>-56a<sub>4</sub>. The coils 56a<sub>1</sub>-56a<sub>4</sub> are situated outside the column 51 at the same position along the axis A. The center of each coil 56a<sub>1</sub>-56a<sub>4</sub> is laterally displaced from the center of the column 51, wherein the respective centers of the coils 56a<sub>1</sub>-25 56a<sub>4</sub> are situated equi-angularly (90° in the depicted configuration) relative to each other. Each of the coils 56a<sub>1</sub>-56a<sub>4</sub> has a respective pair of wires 57 extending therefrom. To minimize external effects of magnetic fields generated by the currents flowing therein, each pair of wires 57 is twisted, as discussed in the first representative embodiment.

30 Because the four coils 56a<sub>1</sub>-56a<sub>4</sub> are situated with offset centers as noted above, the magnitude and direction of the composite magnetic field generated by the

set of coils 56a can be finely varied over a wide range by adjusting the respective electrical current flowing in each individual coil 56a<sub>1</sub>-56a<sub>4</sub>. Thus, a composite magnetic field can be generated having a magnitude and direction sufficient to cancel an otherwise interfering external magnetic field, thereby canceling the effect

5 of the external magnetic field.

The coil set 56b shown in FIG. 3(c) comprises eight individual coils 56b<sub>1</sub>-56b<sub>8</sub>. Each of the individual coils 56b<sub>1</sub>-56b<sub>8</sub> has a circular configuration, and the coils 56b<sub>1</sub>-56b<sub>8</sub> are arranged equi-angularly relative to each other on a circle 58 outside the column 51. However, the operational result of the coil set 56b is the

10 same as of the coil set 56a in FIG. 3(b).

For cancellation of an actual interfering magnetic field, a combination of two or more of the first, second, and third representative embodiments can be utilized.

In the first, second, and third representative embodiments, the coils 36, 46, and 56, respectively, are all in respective transverse planes that are perpendicular to the axis A. Alternatively, all or some of these coils can be placed at an incline 15 relative to the respective transverse planes (e.g., see the eighth representative embodiment).

Also, in the first, second, and third representative embodiments, the coils 36, 46, 56 are situated relative to the respective column at respective positions that are 20 within the scope of the phrase "on or near" the respective column.

With the first, second, and third representative embodiments, very accurate and precise cancellation of an external magnetic field can be achieved, even under conditions in which the distribution of the external magnetic field is not uniform. Also, because this cancellation is achieved using coils situated on or near the 25 respective columns, no extra space is required for shielding, which reduces the mass and volume of shielding that actually is used.

#### Fourth Representative Embodiment

The first, second, and third representative embodiments are effective for 30 canceling the effects of external magnetic fields. However, if (1) components of the external magnetic field have a direction parallel to the axis A as well as transverse to

the axis A, (2) the external magnetic field has a complex profile, or (3) the external magnetic field is highly non-uniform, then extremely precise and complex control of the respective electrical currents in the individual coils is required to achieve satisfactory cancellation of the effects of such fields and a desired distribution of

5 magnetic field within the column. For example, a situation could arise in which an external magnetic field extending in the axial direction is effectively canceled, but another external magnetic field extending transversely to the axis is not sufficiently canceled. This fourth representative embodiment is configured to address a situation such as one of these.

10 Reference is made to FIG. 4, in which are depicted a column 61, a vacuum chamber 62, a vacuum port 63, an electron-beam source 64 (that produces an electron beam 65), a substrate stage 66, magnetic shields 67, active-canceler coil sets 68 (with corresponding connecting wires 69), openings (or gaps) 70 in the column 61, and an external magnetic field (arrows 71).

15 In the depicted configuration, the active-canceler coil sets 68 (a total of five sets) are situated proximally to the openings 70 in the column 61. Thus, the active-canceler coil sets 68 are situated in a manner similar to the first, second, and third representative embodiments.

20 The magnetic shield 67 comprises an anisotropic magnetic material (such as grain-oriented silicon steel). The shield 67 is configured such that the direction having the least resistance to magnetic flux is as indicated by the arrows 72. By configuring the magnetic shield 67 in this manner, the direction of an external magnetic field leaking into the column 61 can be aligned with a component of the field extending in the direction of the optical axis A (vertical direction in the figure),  
25 thereby reducing the component of the field extending in the transverse direction (horizontal direction in the figure). Effective cancellation of the component of the field extending in the axial direction can be achieved primarily through the action of the active-canceler coil sets 68. The reduction of the transverse component (to which the sensitivity of the charged particle beam 65 is high) eases achieving the  
30 desired control of the external field because it allows attention to be given to

canceling the magnetic field in the axial direction (to which the sensitivity of the beam 65 is low).

#### Fifth Representative Embodiment

5 This embodiment is depicted in FIG. 5. A system according to this embodiment is configured similarly to the fourth representative embodiment, except that, instead of using an anisotropic magnetic material for the magnetic shield 87, a magnetic-shielding material such as Permalloy is used. The shield material is magnetically partitioned as shown in the figure to provide the most unobstructed 10 flow of magnetic flux in the axial direction in the shield 87. Thus, the same operational effect is obtained as in the fourth representative embodiment (FIG. 4).

In a CPB optical system especially as used in a CPB microlithography system, the effect of a lateral magnetic field on system performance is about 100 times greater than the effect of an axially oriented magnetic field. Hence, in this 15 representative embodiment, the shield 87 is configured to achieve high suppression of lateral magnetic fields, and the effects of axially oriented magnetic fields are reduced by active-canceler coils such as in any of the first, second, third, and fourth representative embodiments. As an alternative, if conditions dictate, the axially oriented fields can be suppressed using the external magnetic shield 87, and 20 reduction of the effects of the transverse fields is achieved using the active-canceler coils.

Thus, in any event, the effects of external magnetic fields in both the axial and transverse directions are controllably reduced. Since transversely oriented fields tend to have higher magnitude in regions where gaps are larger (such as at the 25 substrate stage), this representative embodiment can be most effective when applied at these locations.

If the material of the shield 87 is partitioned according to this representative embodiment, gaps will exist between adjacent segments of the shielding material. Because these gaps can be a source of direct leakage of magnetic flux through the 30 gaps directly into the CPB optical system inside the column, the gaps should be kept as small as possible. Leakage of magnetic flux can be essentially eliminated by

keeping these gaps less than approximately 0.5 mm wide. Direct leakage of flux through the gaps also can be reduced by staggering the gaps (i.e., offsetting their positions relative to each other), and by configuring the shield as a laminate of multiple layers of shielding material, thereby enhancing the overall shielding effect.

5

#### Sixth Representative Embodiment

This embodiment is shown in FIG. 6. The depicted system includes an illumination-optical-system (IOS) column 91, an exposure-optical-system (EOS) column 92, a vacuum port 93, and a vacuum chamber 94. The columns 91, 92

10 typically extend along an axis A. The embodiment also includes active-canceler coil sets 95, 96 associated with an opening (or gap) 97 between the columns 91, 92, and an active-canceler coil set 98 associated with an opening (or gap) 99 between the column 92 and the vacuum chamber 94. The vacuum port 93 has an associated opening (or gap) 100. The axis A can be regarded as the optical axis of the depicted system and as the z-axis of a three-dimensional coordinate system. In the figure, "horizontal" is the left-right axis (e.g. x-axis), and "vertical" is the up-down axis (z-axis).

Without the coils sets 95, 96, 98, external magnetic fields could penetrate through the openings 97, 99, 100 into the interior of the columns 91, 92 and vacuum

20 chamber 94 toward the axis A, potentially disrupting proper operation of the depicted CPB optical system. In this embodiment penetration of external magnetic fields is prevented by appropriate energization of the active-canceler coil sets 95, 96, 98. Each of the coil sets 95, 96, 98 extends in a respective plane (x-y plane) perpendicular to the axis A. The coil set 95 is situated on the IOS column 91 proximally to the opening 97; the coil set 96 is situated on the EOS column 92 proximally to the opening 97; and the coil set 98 is situated on the EOS column 92 proximally to the opening 99. Respective electrical currents supplied to the coil sets 95, 96, 98 create respective magnetic fields  $B_1$ ,  $B_2$ ,  $B_3$  that extend parallel to the axis A that cancel external magnetic fields (magnetic flux) flowing in the opposite direction externally to the columns. Each of the three coil sets 95, 96, 98 in FIG. 6 is driven by a separate respective power supply (not shown) capable of adjusting the

individual coil currents as required to minimize incursion of the external magnetic fields into the columns.

#### Seventh Representative Embodiment

5 This embodiment is shown in FIGS. 7(a)-7(c). The depicted system includes an illumination-optical-system (IOS) column 101, an exposure-optical-system (EOS) column 102, a vacuum port 103, and a vacuum chamber 104. The columns 101, 102 typically extend along the axis A. The embodiment also includes an active-canceler coil set 105 associated with an opening (or gap) 107 between the 10 columns 101, 102, an active-canceler coil set 106 associated with an opening (or gap) 110 into the vacuum port 103, and an active-canceler coil set 108 associated with an opening (or gap) 109 between the column 102 and the vacuum chamber 104. The axis A can be regarded as the optical axis of the depicted system, wherein the optical axis is parallel to a z-axis of a three-dimensional coordinate system.

15 Without the coil sets 105, 106, 108 external magnetic fields could penetrate through the openings 107, 109, 110 into the interior of the columns 101, 102 and vacuum chamber 104 toward the axis A, potentially disrupting proper operation of the depicted CPB optical system. In this embodiment penetration of external magnetic fields is prevented by appropriate energization of the active-canceler coil sets 105, 106, 108 associated with the respective openings 107, 109, 110 (FIG. 7(a)). Each of the coil sets 105, 106, 108 is configured to generate (when electrically energized) a respective magnetic field extending horizontally in the figure (i.e., in the x-axis and y-axis directions perpendicularly to the axis A). Electrical energization is performed by respective power supplies (not shown) capable of 20 adjusting the individual coil currents as required to minimize incursions of the external magnetic fields to the charged particle beam inside the columns.

25

FIG. 7(b) shows a transverse (x-y plane) section of the coil set 105 and an elevational view of the coil 105a in the y-z plane. An oblique view of the coil 105a is shown in FIG. 7(c). As shown, the coil set 105 comprises four individual coils 30 105a-105d. The coils 105a and 105c generate respective magnetic fields extending in the x-axis direction, and the coils 105b and 105d generate respective magnetic

fields extending in the y-axis direction. By individually controlling the respective electrical currents delivered to the coils 105a-105d, the resulting magnetic fields produced by the coils can be configured to cancel a horizontal external magnetic field. The configuration of the coil set 108 of FIG. 7(a) is essentially the same as the 5 depicted configuration of the coil set 105. The coil set 106 is wound around the vacuum port 103 in a manner sufficient to generate a magnetic field in the x-axis direction (which is the axial direction of the vacuum port 103).

#### Eighth Representative Embodiment

10 This embodiment is depicted in FIG. 8. The depicted system includes an illumination-optical-system (IOS) column 111, an exposure-optical-system (EOS) column 112, a vacuum port 113, and a vacuum chamber 114. The columns 111, 112 typically extend along the axis A. The columns 111, 112 are separated from each other by an opening (or gap) 117, and the column 112 and vacuum chamber 114 are 15 separated from each other by an opening (or gap) 118. Another opening (or gap) 119 is associated with the vacuum port 113. The embodiment also includes an active-canceler coil set 115 associated with the IOS column 111, and an active-canceler coil set 116 associated with the EOS column 112. The axis A can be regarded as the optical axis of the depicted system, wherein the optical axis is 20 parallel to a z-axis of a three-dimensional coordinate system.

As shown in FIG. 8, each of the coil sets 115, 116 is wound diagonally on the respective column 111, 112 of the illumination-optical system and exposure-optical system, respectively. Respective electrical currents flowing in the coil sets cause the coils in the coil sets to generate magnetic fields, outside the respective 25 columns, extending in respective directions that are oblique to the axis A. Thus, whenever an external magnetic flux is present that extends obliquely to the axis A, the coil sets 115, 116 effectively cancel the external magnetic flux and hence remove any deleterious effects of the external magnetic field.

The sixth, seventh, and eighth representative embodiments described above 30 provide additional examples of coil sets being located "on or near" the respective columns. The respective coil sets in these embodiments cancel external magnetic

fields extending in the z-axis direction (FIG. 6), in the x- and y-axis directions (FIG. 7(a)), and in directions oblique to the z-axis direction (FIG. 8). Hence, whenever it is desired to cancel external magnetic fields having directional components extending in multiple axial directions, the configurations of FIGS. 6, 7(a), and 8 can

5 be combined to achieve effective cancellation of the three-dimensional external fields. Even more effective shielding can be achieved by including an external shield such as shown in FIG. 4 or FIG. 5.

Whereas the invention has been described in connection with multiple representative embodiments, it will be understood that the invention is not limited to 10 those embodiments. On the contrary, the invention is intended to encompass all modifications, alternatives, and equivalents as may be included within the spirit and scope of the invention, as defined by the appended claims.

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65  
66  
67  
68  
69  
70  
71  
72  
73  
74  
75  
76  
77  
78  
79  
80  
81  
82  
83  
84  
85  
86  
87  
88  
89  
90  
91  
92  
93  
94  
95  
96  
97  
98  
99  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135  
136  
137  
138  
139  
140  
141  
142  
143  
144  
145  
146  
147  
148  
149  
150  
151  
152  
153  
154  
155  
156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180  
181  
182  
183  
184  
185  
186  
187  
188  
189  
190  
191  
192  
193  
194  
195  
196  
197  
198  
199  
200  
201  
202  
203  
204  
205  
206  
207  
208  
209  
210  
211  
212  
213  
214  
215  
216  
217  
218  
219  
220  
221  
222  
223  
224  
225  
226  
227  
228  
229  
230  
231  
232  
233  
234  
235  
236  
237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
289  
290  
291  
292  
293  
294  
295  
296  
297  
298  
299  
299  
300  
301  
302  
303  
304  
305  
306  
307  
308  
309  
309  
310  
311  
312  
313  
314  
315  
316  
317  
318  
319  
319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
369  
370  
371  
372  
373  
374  
375  
376  
377  
378  
379  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398  
399  
399  
400  
401  
402  
403  
404  
405  
406  
407  
408  
409  
409  
410  
411  
412  
413  
414  
415  
416  
417  
418  
419  
419  
420  
421  
422  
423  
424  
425  
426  
427  
428  
429  
429  
430  
431  
432  
433  
434  
435  
436  
437  
438  
439  
439  
440  
441  
442  
443  
444  
445  
446  
447  
448  
449  
449  
450  
451  
452  
453  
454  
455  
456  
457  
458  
459  
459  
460  
461  
462  
463  
464  
465  
466  
467  
468  
469  
469  
470  
471  
472  
473  
474  
475  
476  
477  
478  
479  
479  
480  
481  
482  
483  
484  
485  
486  
487  
488  
489  
489  
490  
491  
492  
493  
494  
495  
496  
497  
498  
499  
499  
500  
501  
502  
503  
504  
505  
506  
507  
508  
509  
509  
510  
511  
512  
513  
514  
515  
516  
517  
518  
519  
519  
520  
521  
522  
523  
524  
525  
526  
527  
528  
529  
529  
530  
531  
532  
533  
534  
535  
536  
537  
538  
539  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
589  
590  
591  
592  
593  
594  
595  
596  
597  
598  
599  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649  
649  
650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708  
709  
709  
710  
711  
712  
713  
714  
715  
716  
717  
718  
719  
719  
720  
721  
722  
723  
724  
725  
726  
727  
728  
729  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
739  
740  
741  
742  
743  
744  
745  
746  
747  
748  
749  
749  
750  
751  
752  
753  
754  
755  
756  
757  
758  
759  
759  
760  
761  
762  
763  
764  
765  
766  
767  
768  
769  
769  
770  
771  
772  
773  
774  
775  
776  
777  
778  
779  
779  
780  
781  
782  
783  
784  
785  
786  
787  
788  
789  
789  
790  
791  
792  
793  
794  
795  
796  
797  
798  
799  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
819  
820  
821  
822  
823  
824  
825  
826  
827  
828  
829  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
879  
880  
881  
882  
883  
884  
885  
886  
887  
888  
889  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
939  
940  
941  
942  
943  
944  
945  
946  
947  
948  
949  
949  
950  
951  
952  
953  
954  
955  
956  
957  
958  
959  
959  
960  
961  
962  
963  
964  
965  
966  
967  
968  
969  
969  
970  
971  
972  
973  
974  
975  
976  
977  
978  
979  
979  
980  
981  
982  
983  
984  
985  
986  
987  
988  
989  
989  
990  
991  
992  
993  
994  
995  
996  
997  
998  
999  
999  
1000  
1001  
1002  
1003  
1004  
1005  
1006  
1007  
1008  
1009  
1009  
1010  
1011  
1012  
1013  
1014  
1015  
1016  
1017  
1018  
1019  
1019  
1020  
1021  
1022  
1023  
1024  
1025  
1026  
1027  
1028  
1029  
1029  
1030  
1031  
1032  
1033  
1034  
1035  
1036  
1037  
1038  
1039  
1039  
1040  
1041  
1042  
1043  
1044  
1045  
1046  
1047  
1048  
1049  
1049  
1050  
1051  
1052  
1053  
1054  
1055  
1056  
1057  
1058  
1059  
1059  
1060  
1061  
1062  
1063  
1064  
1065  
1066  
1067  
1068  
1069  
1069  
1070  
1071  
1072  
1073  
1074  
1075  
1076  
1077  
1078  
1079  
1079  
1080  
1081  
1082  
1083  
1084  
1085  
1086  
1087  
1088  
1089  
1089  
1090  
1091  
1092  
1093  
1094  
1095  
1096  
1097  
1098  
1099  
1099  
1100  
1101  
1102  
1103  
1104  
1105  
1106  
1107  
1108  
1109  
1109  
1110  
1111  
1112  
1113  
1114  
1115  
1116  
1117  
1118  
1119  
1119  
1120  
1121  
1122  
1123  
1124  
1125  
1126  
1127  
1128  
1129  
1129  
1130  
1131  
1132  
1133  
1134  
1135  
1136  
1137  
1138  
1139  
1139  
1140  
1141  
1142  
1143  
1144  
1145  
1146  
1147  
1148  
1149  
1149  
1150  
1151  
1152  
1153  
1154  
1155  
1156  
1157  
1158  
1159  
1159  
1160  
1161  
1162  
1163  
1164  
1165  
1166  
1167  
1168  
1169  
1169  
1170  
1171  
1172  
1173  
1174  
1175  
1176  
1177  
1178  
1179  
1179  
1180  
1181  
1182  
1183  
1184  
1185  
1186  
1187  
1188  
1189  
1189  
1190  
1191  
1192  
1193  
1194  
1195  
1196  
1197  
1198  
1199  
1199  
1200  
1201  
1202  
1203  
1204  
1205  
1206  
1207  
1208  
1209  
1209  
1210  
1211  
1212  
1213  
1214  
1215  
1216  
1217  
1218  
1219  
1219  
1220  
1221  
1222  
1223  
1224  
1225  
1226  
1227  
1228  
1229  
1229  
1230  
1231  
1232  
1233  
1234  
1235  
1236  
1237  
1238  
1239  
1239  
1240  
1241  
1242  
1243  
1244  
1245  
1246  
1247  
1248  
1249  
1249  
1250  
1251  
1252  
1253  
1254  
1255  
1256  
1257  
1258  
1259  
1259  
1260  
1261  
1262  
1263  
1264  
1265  
1266  
1267  
1268  
1269  
1269  
1270  
1271  
1272  
1273  
1274  
1275  
1276  
1277  
1278  
1279  
1279  
1280  
1281  
1282  
1283  
1284  
1285  
1286  
1287  
1288  
1289  
1289  
1290  
1291  
1292  
1293  
1294  
1295  
1296  
1297  
1298  
1299  
1299  
1300  
1301  
1302  
1303  
1304  
1305  
1306  
1307  
1308  
1309  
1309  
1310  
1311  
1312  
1313  
1314  
1315  
1316  
1317  
1318  
1319  
1319  
1320  
1321  
1322  
1323  
1324  
1325  
1326  
1327  
1328  
1329  
1329  
1330  
1331  
1332  
1333  
1334  
1335  
1336  
1337  
1338  
1339  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346  
1347  
1348  
1349  
1349  
1350  
1351  
1352  
1353  
1354  
1355  
1356  
1357  
1358  
1359  
1359  
1360  
1361  
1362  
1363  
1364  
1365  
1366  
1367  
1368  
1369  
1369  
1370  
1371  
1372  
1373  
1374  
1375  
1376  
1377  
1378  
1379  
1379  
1380  
1381  
1382  
1383  
1384  
1385  
1386  
1387  
1388  
1389  
1389  
1390  
1391  
1392  
1393  
1394  
1395  
1396  
1397  
1398  
1399  
1399  
1400  
1401  
1402  
1403  
1404  
1405  
1406  
1407  
1408  
1409  
1409  
1410  
1411  
1412  
1413  
1414  
1415  
1416  
1417  
1418  
1419  
1419  
1420  
1421  
1422  
1423  
1424  
1425  
1426  
1427  
1428  
1429  
1429  
1430  
1431  
1432  
1433  
1434  
1435  
1436  
1437  
1438  
1439  
1439  
1440  
1441  
1442  
1443  
1444  
1445  
1446  
1447  
1448  
1449  
1449  
1450  
1451  
1452  
1453  
1454  
1455  
1456  
1457  
1458  
1459  
1459  
1460  
1461  
1462  
1463  
1464  
1465  
1466  
1467  
1468  
1469  
1469  
1470  
1471  
1472  
1473  
1474  
1475  
1476  
1477  
1478  
1479  
1479  
1480  
1481  
1482  
1483  
1484  
1485  
1486  
1487  
1488  
1489  
1489  
1490  
1491  
1492  
1493  
1494  
1495  
1496  
1497  
1498  
1499  
1499  
1500  
1501  
1502  
1503  
1504  
1505  
1506  
1507  
1508  
1509  
1509  
1510  
1511  
1512  
1513  
1514  
1515  
1516  
1517  
1518  
1519  
1519  
1520  
1521  
1522  
1523  
1524  
1525  
1526  
1527  
1528  
1529  
1529  
1530  
1531  
1532  
1533  
1534  
1535  
1536  
1537  
1538  
1539  
1539  
1540  
1541  
1542  
1543  
1544  
1545  
1546  
1547  
1548  
1549  
1549  
1550  
1551  
1552  
1553  
1554  
1555  
1556  
1557  
1558  
1559  
1559  
1560  
1561  
1562  
1563  
1564  
1565  
1566  
1567  
1568  
1569  
1569  
1570  
1571  
1572  
1573  
1574  
1575  
1576  
1577  
1578  
1579  
1579  
1580  
1581  
1582  
1583  
1584  
1585  
1586  
1587  
1588  
1589  
1589  
1590  
1591  
1592  
1593  
1594  
1595  
1596  
1597  
1598  
1599  
1599  
1600  
1601  
1602  
1603  
1604  
1605  
1606  
1607  
1608  
1609  
1609  
1610  
1611  
1612  
1613  
1614  
1615  
1616  
1617  
1618  
1619  
1619  
1620  
1621  
1622  
1623  
1624  
1625  
1626  
1627  
1628  
1629  
1629  
1630  
1631  
1632  
1633  
1634  
1635  
1636  
1637  
1638  
1639  
1639  
1640  
1641  
1642  
1643  
1644  
1645  
1646  
1647  
1648  
1649  
1649  
1650  
1651  
1652  
1653  
1654  
1655  
1656  
1657  
1658  
1659  
1659  
1660  
1661  
1662  
1663  
1664  
1665  
1666  
1667  
1668  
1669  
1669  
1670  
1671  
1672  
1673  
1674  
1675  
1676  
1677  
1678  
1679  
1679  
1680  
1681  
1682  
1683  
1684  
1685  
1686  
1687  
1688  
1689  
1689  
1690  
1691  
1692  
1693  
1694  
1695  
1696  
1697  
1698  
1699  
1699  
1700  
1701  
1702  
1703  
1704  
1705  
1706  
1707  
1708  
1709  
1709  
1710  
1711  
1712  
1713  
1714  
1715  
1716  
1717  
1718  
1719  
1719  
1720  
1721  
1722  
1723  
1724  
1725  
1726  
1727  
1728  
1729  
1729  
1730  
1731  
1732  
1733  
1734  
1735  
1736  
1737  
1738  
1739  
1739  
1740  
1741  
1742  
1743  
1744  
1745  
1746  
1747  
1748  
1749  
1749  
1750  
1751  
1752  
1753  
1754  
1755  
1756  
1757  
1758  
1759  
1759  
1760  
1761  
1762  
1763  
1764  
1765  
1766  
1767  
1768  
1769  
1769  
1770  
1771  
1772  
1773  
1774  
1775  
1776  
1777  
1778  
1779  
1779  
1780  
1781  
1782  
1783  
1784  
1785  
1786  
1787  
1788  
1789  
1789  
1790  
1791  
1792  
1793  
1794  
1795  
1796  
1797  
1798  
1799  
1799  
1800  
1801  
1802  
1803  
1804  
1805  
1806  
1807  
1808  
1809  
1809  
1810  
1811  
1812  
1813  
1814  
1815  
1816  
1817  
1818  
1819  
1819  
1820  
1821  
1822  
1823  
1824  
1825  
1826  
1827  
1828  
1829  
1829  
1830  
1831  
1832  
1833  
1834  
1835  
1836  
1837  
1838  
1839  
1839  
1840  
1841  
1842  
1843  
1844  
1845  
1846  
1847  
1848  
1849  
1849  
1850  
1851  
1852  
1853  
1854  
1855  
1856  
1857  
1858  
1859  
1859  
1860  
1861  
1862  
1863  
1864  
1865  
1866  
1867  
1868  
1869  
1869  
1870  
1871  
1872  
1873  
1874  
1875  
1876  
1877  
1878  
1879  
1879  
1880  
1881  
1882  
1883  
1884  
1885  
1886  
1887  
1888  
1889  
1889  
1890  
1891  
1892  
1893  
1894  
1895  
1896  
1897  
1898  
1899  
1899  
1900  
1901  
1902  
1903  
1904  
1905  
1906  
1907  
1908  
1909  
1909  
1910  
1911  
1912  
1913  
1914  
1915  
1916  
1917  
1918  
1919  
1919  
1920  
1921  
1922  
1923  
1924  
1925  
1926  
1927  
1928  
1929  
1929  
1930  
1931  
1932  
1933  
1934  
1935  
1936  
1937  
1938  
1939  
1939  
1940  
1941  
1942  
1943  
1944  
1945  
1946  
1947  
1948  
1949  
1949  
1950  
1951  
1952  
1953  
1954  
1955  
1956  
1957  
1958  
1959  
1959  
1960  
1961  
1962  
1963  
1964  
1965  
1966  
1967  
1968  
1969  
1969  
1970  
1971  
1972  
1973  
1974  
1975  
1976  
1977  
1978  
1979  
1979  
1980  
1981  
1982  
1983  
1984  
1985  
1986  
1987  
1988  
1989  
1989  
1990  
1991  
1992  
1993  
1994  
1995  
1996  
1997  
1998  
1999  
1999  
2000  
2001  
2002  
2003  
2004  
2005  
2006  
2007  
2008  
200